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Toxic Harvest: Metal Contaminants in Fluted Pumpkin (*Telfairia occidentalis*) Cultivated around Quarry Sites in Akamkpa, Nigeria

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Abstract

This study assessed the accumulation of heavy metals in fluted pumpkins (Telfairia occidentalis) grown near quarry sites in Awi and Njagachan communities between January and July 2023 using atomic absorption spectrophotometry after wet digestion. The mean concentrations of lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), and selenium (Se) were found to range from 0.72–1.56 mg/kg, 0.42–0.99 mg/kg, 0.04–0.10 mg/kg, 0.51–8.89 mg/kg, and 0.05–0.19 mg/kg, respectively. The Pb and Cd levels exceeded the FAO/WHO permissible limits for leafy vegetables. The estimated daily intake (EDI) for Pb, Cd, and Hg also surpassed their recommended daily intake (RDI), with Pb and Cd exceeding upper tolerable intake levels. While the target hazard quotient (THQ) for all metals except arsenic was below 1, the hazard index (HI) for all metals exceeded unity, indicating potential non-carcinogenic risks. Furthermore, the incremental lifetime cancer risk (ILCR) for Cd and As surpassed the regulatory threshold (10^{-4}), as did the cumulative cancer risk for all quarries. The findings highlight the potential toxicological risks posed by consuming fluted pumpkin from these areas, especially due to Pb, Cd, and As contamination. The study strongly recommends further investigation of heavy metal accumulation in other crops in the region to safeguard public health, promote responsible consumption, and mitigate long-term health risks. Urgent regulatory interventions are also advised to manage contamination sources near agricultural sites.

Introduction: Environmental pollution due to heavy metals has become a critical issue worldwide, particularly in areas of intense industrial and mining activities (Singh, Nayak, & Dwivedi, 2021). The release of these toxic metals into the environment is exacerbated by various anthropogenic activities, including quarrying, which is a major source of environmental degradation in many developing nations (Omoniyi, Akinyemi, & Bello, 2020). Quarrying activities, which involve the extraction of valuable minerals from the earth, often result in significant environmental contamination, particularly through the dispersal of particulate matter and heavy metals into nearby ecosystems (Adjei, Osei, & Ansah, 2019). In Akamkpa Local Government Area (LGA) of Cross River State, Nigeria, there are several active quarries, notably in the Awi and Njagachan communities, whose proximity to farmlands raises concerns about the potential for heavy metal contamination in agricultural produce (Okorie Ikedi, & Nnamdi, 2023). The environmental consequences of quarrying activities, particularly metal pollution of soils, have garnered increasing attention in recent years. In Nigeria, the expansion of quarries has intensified, especially in regions like Akamkpa, Cross River State, which host a significant number of these operations. Two prominent communities impacted by these activities are Awi and Njagachan. These quarries extract materials such as limestone and granite, releasing heavy metals into surrounding soils and posing potential threats to local ecosystems and human health (**Olujobi & Ogunniyi, 2020**). One of the major concerns related to quarrying is soil contamination by heavy metals. Metals such as lead (Pb), cadmium (Cd), nickel (Ni), and zinc (Zn) are non-biodegradable, meaning they persist in the environment and can accumulate in soils over time (**Nnadi & Nweke, 2021**). According to a study by Adewole and Adesina (2021), quarrying operations release particulate matter and heavy metals into soils, leading to contamination of nearby farmlands. Similarly, studies in other parts of Nigeria, such as **Ogundele, (2019**), have shown that quarrying activities lead to elevated concentrations of heavy metals, such as Pb, Cd, and Zn, in soils surrounding the quarries. This accumulation can significantly affect soil fertility and lead to the uptake of these metals by crops, thereby introducing them into the food chain. Furthermore, the runoff from contaminated soils can pollute nearby water bodies, negatively impacting aquatic life (Akan, Sodipo, & Mohammed, 2022)**.** For the agricultural communities in Awi and Njagachan, these pollutants pose substantial risks, not only to the crops they cultivate but also to the residents who consume these crops, potentially exposing them to harmful levels of heavy metals (**Okorie et al., 2023**).

One of the most widely cultivated crops in these areas is the fluted pumpkin (*Telfairia occidentalis*), a nutrient-dense vegetable widely consumed across Nigeria (Ene-Obong, Iweala, & Abah, 2022). Fluted pumpkin is not only a staple in the diets of many communities but also a significant source of income for local farmers (Emuekele, Ogwueleka, & Afolabi, 2020). However, there is growing concern that crops cultivated near quarries may accumulate toxic metals such as lead, cadmium, nickel, zinc, and copper, which are known to be harmful to both plants and humans when present at elevated levels (Agrawal, Singh, & Dutta, 2021). The accumulation of heavy metals in vegetables poses a serious public health risk, as these metals can enter the food chain (Olowoyo, Ogunfowokan, & Okonkwo, 2020). Long-term exposure to heavy metals, even at low levels, can lead to chronic health conditions, including neurological damage, kidney disease, and an increased risk of cancer (**Alissa & Ferns, 2017**). For instance, lead (Pb) is a neurotoxin that affects cognitive development in children and can cause cardiovascular and renal dysfunction in adults (Lanphear, Rauch, Auinger, Allen, & Hornung, 2018). Cadmium (Cd) exposure has been linked to bone demineralization and kidney damage, while nickel (Ni) can induce allergic reactions and respiratory issues (Khan, Niazi, & Shahid, 2022). Despite the widespread quarrying activities in Akamkpa LGA, there has been limited research on the impacts of these operations on public health via consumption of cultivated crop in the area. While several studies have documented heavy metal contamination in soils near quarry sites (Nnadozie, Ekene, & Akeju, 2021), there is a significant gap in research focused on the direct evaluation of heavy metal concentrations in crops, particularly in the context of quarrying activities (Fashola, Ngole-Jeme, & Baderoon, 2021). This study seeks to evaluate the levels of heavy metal accumulation in fluted pumpkins cultivated near the Awi and Njagachan quarry sites in Akamkpa LGA and to assess the potential human health implications of consuming these vegetables. By focusing solely on the plant material without assessing the soil, this research aims to provide direct evidence of contamination in the edible parts of the crop, which is critical for assessing dietary exposure risks. Given the widespread consumption of these vegetables in local diets, understanding the level of contamination is essential for protecting public health.

Materials and Methods: **The study area**: Cross River State Nigeria is located at latitude 5.8702 ºN and longitude 8.5988 ºE. Calabar is the capital of the State. Cross River State has a total area of 20,156km^2 square kilometres and is bordered in the east by Cameroon, in the north by Benue state, on the west by Ebonyi State and Akwa Ibom State on the south west. Cross River State is made up of 18 Local Government Areas. Akamkpa the largest local governments in Cross River state and is located between latitude 5.1667 ºN and 5.5333 ^{0}N, and Longitude 8.2333 ºE and 8.6333 ºE (FIG. 1). It has an area of 5,003 square kilometres (1.932 sqm) with an elevation of 50-200 meters above sea level and a projected population of 200,100 (population Stat, 2020). The vegetation of Akamkpa Local Government Area ranges from mangrove swamps through rainforest, to derived Savannah. The geology of Akamkpa region is made up of rocks of the Oban Massif belonging to the Precambrian Basement Complex rocks of Nigeria. These rocks are overlain by the sedimentary rocks of Cretaceous age (Davidson *et al*, 2019). Akamkpa has the largest stone deposit in the state with both small- and large-scale quarries scattered the length and breadth of the local government. The major occupation of the people living in the study area includes farming (in subsistent and commercial scale), mining (quarrying), fishing and trading.

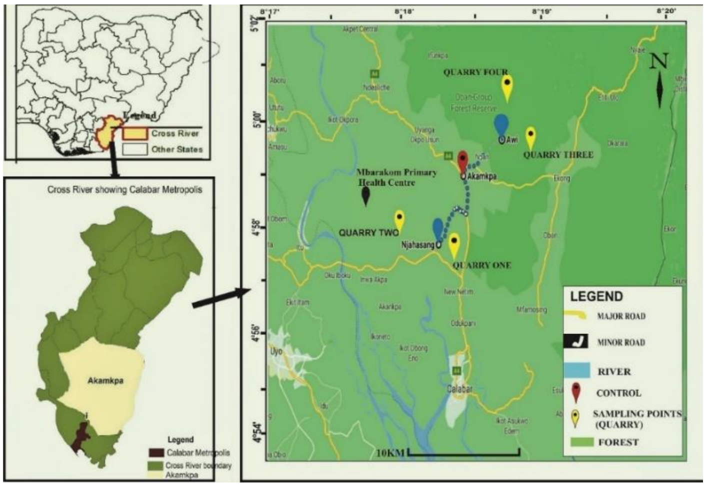

FIG. 1: Map of study area showing sample locations

Sample collection, Preparation and Analysis: Four quarries (Saturn and Twin Brother quarries in Awi, and Fuhua and Ding-zing quarries in Njagachang) were studied. Fluted pumpkin samples were harvested monthly from five farms (100 meters apart) near each quarry between January and July 2023. Samples were collected by cutting stems 10 cm above the ground, placed in black polyethylene bags, and transported to the University of Calabar laboratory. Control samples were obtained from Akamkpa town, free of quarry activities. Composite samples for each quarry were prepared by pooling the five farm samples, air-dried for five days, oven-dried at 40°C for two hours, and ground into fine powder. One gram of each sample was digested with 20 mL nitric acid on a hot plate. Metal concentrations were analyzed using a Shimadzu AA-6800 Atomic Absorption Spectrophotometer (Japan).

Analytical quality assurance: To ensure the reliability and accuracy of findings, meticulous protocols were followed. Mortar and pestle were thoroughly cleaned between samples to prevent cross-contamination. Each composite sample underwent triplicate analysis to confirm consistency. Analytical-grade nitric acid (Riedel-deHaen, Germany) was used for digestion and preservation. To validate results, Standard Reference Material (IAEA-336 lichen) was analyzed, and the measured values were compared against certified reference values, ensuring the dependability of the analytical procedures.

Potential Human Health Assessment: The **US-EPA (1989)** recommended health risk assessment model was used to estimate dietary intake levels and the potentials for both carcinogenic and non-carcinogenic hazards associated with lead, cadmium, mercury, arsenic and selenium exposure from consuming fluted pumpkins from the study area.

Assessment of Non Carcinogenic Risk : The non-carcinogenic health risk of the metals was initially assessed by estimating the level of exposure through dietary intake, using the Estimated Daily Intake (EDI). Subsequently, the individual toxicity or non-carcinogenic risk for each metal was evaluated using the Target Hazard Quotient (THQ), while the combined risk from multiple metals was determined through the Hazard Index (HI).

Estimated Daily Intake (EDI)

The Estimated Daily Intake (EDI) of each metal was determined according to Addo, Darko, Gordon, Nyarko, (2013) using equation 1

$$EDI = \frac{EF \times ED \times DIV \times Cm}{BAW \times AT} \quad \text{...} (1)$$

Where: EF = exposure frequency (350 days/year), ED = exposure duration (54 years), DIV = average daily intake of vegetables (65 grams/person/day for Nigerians) (Njoku-Tony, Udofia, Nwoko, Ihejirika, Ebe, Egbuawa, Ezike, 2020), Cm = concentration of metal in edible tissues of *Telfairia occidentalis* (mg/kg), WAB = average adult body weight (60.7 kg), and AT = average exposure time-age (EF x ED). The average daily intake of vegetables (65 grams per person per day) applies to fresh vegetables. The concentration of metals measured in the study, which was based on dry weight, was recalculated using the mean moisture content (8.79%) of edible tissues *Telfairia occidentalis* from the area (Omimakinde, Oguntimehin, Omimakinde, Olaniran, 2018). This was done to ensure consistency between the unit used for average daily intake of vegetables and measured concentration data following **US EPA, (2011)** according to equation 2.

$$Cww = Cdw\left[\frac{100-W}{100}\right] \quad \text{...} (2)$$

Where *Cww* is the wet weight concentration, *Cdw* is the dry weight concentration and *W* is the moisture content.

Target Hazard Quotient (THQ)

Equation (3) was used to estimate the Target Hazard Quotient (THQ).

$$\mathbf{THQ} = \frac{\mathbf{EF \times ED \times DIV \times Cm}}{\mathbf{RfD \times WAB \times AT}} \quad \text{..} [3]$$

RfD represents the oral reference dose for each metal, expressed in mg/kg of body weight per day. The RfD value for Pb (0.0035 mg/kg/day) was sourced from **ATSDR (2019).** The RfD values for Cd (0.001 mg/kg/day), Hg (0.0003 mg/kg/day), and As (0.0003 mg/kg/day) were obtained from the Integrated Risk Information System (**US EPA, 2010**).

Hazard Index (HI)

The hazard index was calculated using equation 4 (Guerra, Trevizam, Muraoka, Marcante, Canniatti-Brazaca, (2012)**.**

$$\mathbf{HI = \Sigma THQ = THQ_{Pb} + THQ_{Cd} + THQ_{Hg} + THQ_{As} + THQ_{Se}} \text{................} [4]$$

ΣTHQ represents the total sum of the target hazard quotients for all the metals being studied. THQ_{Pb} denotes the target hazard quotient for lead, THQ_{Cd} refers to that of cadmium, THQ_{Hg} is for mercury, and THQ_{As} corresponds to arsenic.

Carcinogenic Health Risk Assessment: Carcinogenic risk was assessed as the increased probability of an individual developing cancer as a result of exposure to a carcinogenic or potentially carcinogenic metals through consumption of fluted pumpkins from the study area, using the Incremental Lifetime Cancer Risk (ILCR) metric. The Cumulative Cancer Risk (CCR) was employed to evaluate the overall carcinogenic risk from exposure to multiple carcinogenic metals.

Incremental Lifetime Cancer Risk (ILCR) **:** Incremental cancer risk was computed using equation 5 (Abba, Murtala, Hafeez, Dayyabu, Kamaludeen, aminu, Anosike, & Ezeanyika, (2020).

$$ILCR_m = EDI_m \times CSF_{m}\text{-}oral \text{ ....} [5]$$

Where EDI_m is the estimated daily intake for the metal and CSF_m is the cancer slope factor-oral for the metal.

Cumulative Cancer Risk (CCR)

The cumulative cancer risk (CCR) was computed using equation 6 (Liu, Song, & Tang, (2013))

$$CCR = \sum ILCR = ILCR_{Pb} + ILCR_{Cd} + ILCR_{Hg} + ILCR_{As} \ldots\ldots\ldots\ldots\ldots\ldots [6]$$

Statistical analysis: Statistical analysis was done using IBM SPSS 23.0 software for Windows. Data collected were subjected to statistical test of significance using the Analysis of Variance (ANOVA) test to assess significant variation in metal content of Fluted pumpkins across the quarries. Probabilities less than 0.05 ($p< 0.05$) were considered statistically significant. Independent T Test were used to assess significant variation of in metal content of Fluted pumpkins between the dry and wet seasons. Probabilities less than 0.05 ($p < 0.05$) were considered statistically significant. Pearson product moment correlation coefficient was used to determine the association between metal levels in soil at $a= 0.05$.

Results: Analytical quality assurance: The accuracy and precision of the analytical procedure were assessed by analyzing Standard Reference Material Lichen IAEA-336 alongside our samples. The results obtained were within the range of the certified reference values for the determined elements, confirming the reliability of the method (Table 1).

Table 1: Results of analyzed reference material (Lichen IAEA - 336) compared to the certified reference values (mg/kg).

Element (mg/kg)	Pb	Cd	Cu	Ni	Cr
Analyzed value	5.25	0.140	4.00	1.20	29.18
Reference value	4.2-5.5	0.1-2.34	3.1- 4.1	1.00-1.50	27.00-30.00

Total heavy metal concentrations in fluted pumpkins (*Telfairia occidentalis)*

Results obtained from the determination of total heavy metal concentration in of *T. occidentalis* cultivated around Saturn and Twin Brothers Quarries, Awi and, Fuhua and Ding Zing Quarries, Njagachang, Cross River State during dry and wet seasons are presented in Table 2 and the comparison of metal concentration in soil for dry and wet seasons presented in Figures 6 and 7. Mean metals contents of *T. occidentalis* across the quarries for both dry and wet seasons were of the ranges 0.72 mg/kg -1.56 mg/kg, 0.42 mg/kg - 0.99 mg/kg, 0.04 mg/kg - 0.10 mg/kg, 0.51 mg/kg - 8.89 mg/kg, and 0.05 mg/kg - 0.19 mg/kg for lead, cadmium, mercury, arsenic, and selenium, respectively (Table 2). The differences

Relationship between heavy metal in fluted pumpkin cultivated around quarries:

The relationship between the heavy metals in fluted pumpkin cultivated around Saturn, Twin Brothers, Fuhua and Ding Zing quarries are presented in Table 3.

A significant ($P < 0.01$) strong positive correlation was observed between lead and cadmium ($r = 0.959$), lead and mercury ($r = 0.942$), lead and arsenic ($r = 0.944$) and between lead and selenium ($r = 0.928$) (Table 12). A significant ($P < 0.01$) strong positive correlation was also observed between cadmium and mercury ($r = 0.957$), cadmium and arsenic ($r = 0.969$) and between cadmium and selenium ($r = 0.965$). Strong positive correlation was also observed between mercury and arsenic ($r = 0.934$), mercury and selenium ($r = 0.925$) and between arsenic and selenium ($r = 0.941$), the correlations were significant at 99% confidence level. **Evaluation potential human health risk due to consumption of fluted pumpkin (*Telfairia occidentalis*) cultivated around the quarries:** The estimated daily intake of lead, cadmium, mercury, arsenic and selenium due to the consumption of fluted pumpkin cultivated in the study area is presented in Table 14, and the Target hazard quotient and hazard index presented in Table 15

Estimated Daily Intake (EDI): Average values of EDI (mg/kg b.w. / day) recorded for lead, cadmium, mercury arsenic and selenium across the quarries for wet and dry season were 1.17 and 1,17, 0.61 and 0.78, 0.05 and 0.07, 0.65 and 0.75, and 0.10 and 0.13 respectively (Table 4).

Target Hazard Quotient (THQ): Average values of THQ for lead, cadmium, mercury, arsenic and selenium across the quarries for both dry and wet season were 0.340 and 0.334, 0.635 and 0.774, 0.187 and 0.223, 2.168 and 2.499, and 0.019 and 0.026 respectively (Table 5).

Hazard Index (HI) : The hazard index from this study for both dry and wet seasons were 3.185 and 3.645 for Saturn, 2.646 and 3.08 for Twin Brother, 3.666 and 4.234 for Fuhua and 3.889 and 4.464 for Ding Zing.

***Incremental Life Time Cancer Risk (ILCR)*:** The average incremental life time cancer risk for lead, cadmium and arsenic were 1.8×10^{-6}, 4.9×10^{-2}, 4.5×10^{-2} for 8 Miles market, 1.6×10^{-6}, $4.8 \times 10^{-2}$and 5.1×10^{-2} for Marian market, 2.4×10^{-6}, $4.7 \times 10^{-2}$and 5.9×10^{-2} for Watt market and 2.0×10^{-6}, 4.8×10^{-2} and 5.4×10^{-2} for Mbukpa market

Cumulative Cancer Risk (CCR)

Cumulative cancer risk for dry and wet seasons were $9.4x10^{-2}$ and $1.1x10^{-1}$ for Saturn, $7.9x10^{-2}$ and $1.1x10^{-1}$ for Twin brother, $1.2x10^{-1}$ and $2.8\ x10^{-2}$ for Fuhua, and $1.2x10^{-1}$ and $2.9x10^{-2}$ for Ding Zing.

Dicussion: Total heavy metal concentration in fluted pumpkins (*Telfairia occidentalis)*: Plants, especially those grown in contaminated environments, have a significant potential to uptake harmful metals from the soil and accumulate them in edible parts at concentrations high enough to pose health risks. Consumption of these contaminated plant parts is a key route for metal intoxication. This study evaluated the levels of lead, cadmium, mercury, arsenic, and selenium in *Telfairia occidentalis* (fluted pumpkin), with the aim of assessing potential public health risks. By comparing the metal concentrations in the leaves and tender shoots to international regulatory standards, the study provides critical insights into human exposure to these toxic elements.

TABLE 2
Total heavy metal concentration in fluted pumpkin around quarries for both dry and wet season

		Dry Season					Wet Season				
Station	Metals	Jan	Feb	March	Mean±SD	Range	May	June	July	Mean±SD	Range
Saturn	Pb	0.87	0.93	1.08	0.96±0.09[a]	0.97-1.08	0.96	1.29	1.48	1.24±0.21[a]	0.96-1.48
	Cd	0.56	0.47	0.67	0.57±0.81[a]	0.47-0.67	0.69	0.74	0.74	0.72±0.02[a]	0.69-0.74
	Hg	0.05	0.05	0.06	0.05±0.00[a]	0.05-0.06	0.06	0.06	0.07	0.06±0.00[a]	0.06-0.07
	As	0.67	0.58	0.69	0.65±0.05[a]	0.58-0.69	0.69	0.75	0.75	0.73±0.00[a]	0.69-0.75
	Se	0.08	0.11	0.09	0.09±0.01[a]	0.08-0.11	0.12	0.14	0.11	0.12±0.01[a]	0.11-0.14
Twin Brother	Pb	0.72	0.63	0.82	0.72±0.08[a]	0.72-0.82	0.93	0.83	0.81	0.86±0.05[a]	0.81-0.93
	Cd	0.45	0.42	0.57	0.48±0.06[a]	0.42-0.57	0.62	0.65	0.62	0.63±0.01[b]	0.62-0.65
	Hg	0.04	0.05	0.04	0.04±0.00[a]	0.04-0.05	0.05	0.06	0.05	0.05±0.00[a]	0.05-0.06
	As	0.51	0.54	0.62	0.56±0.04[a]	0.51-0.62	0.59	0.62	0.65	0.62±0.02[a]	0.59-0.65
	Se	0.07	0.05	0.09	0.07±0.01[a]	0.05-0.09	0.09	0.11	0.10	0.10±0.01[a]	0.09-0.11
Fuhua	Pb	0.97	1.36	1.45	1.26±0.21[a]	0.97-1.45	1.02	1.34	1.41	1.26±0.17[a]	1.02-0.41
	Cd	0.74	0.73	0.86	0.78±0.06[a]	0.73-0.86	0.89	0.88	0.96	0.91±0.04[a]	0.88-0.96
	Hg	0.05	0.07	0.08	0.067±0.01[a]	0.05-0.08	0.08	0.08	0.07	0.08±0.00[a]	0.07-0.08
	As	0.69	0.73	0.71	0.71±0.02[a]	0.69-0.73	0.78	0.86	0.85	0.83±0.04[b]	0.78-0.86
	Se	0.11	0.10	0.13	0.11±0.01[a]	0.10-0.13	0.14	0.14	0.17	0.15±0.01[a]	0.14-0.17
Ding/Zing	Pb	1.01	1.27	1.56	1.28±0.22[a]	1.01-1.56	1.32	1.48	1.52	1.44±0.09[a]	1.32-1.52
	Cd	0.67	0.76	0.88	0.77±0.09[a]	0.67-0.88	0.84	0.89	0.99	0.91±0.06[a]	0.84-0.99
	Hg	0.07	0.06	0.08	0.07±0.01[a]	0.06-0.08	0.08	0.09	0.10	0.09±0.01[a]	0.08-0.10
	As	0.72	0.74	0.76	0.74±0.02[a]	0.72-0.76	0.87	0.89	0.88	0.88±0.01[b]	0.87-0.89
	Se	0.09	0.14	0.12	0.12±0.02[a]	0.09-0.14	0.13	0.17	0.19	0.16±0.02[a]	0.13-0.19
Control	Pb	0.09	0.12	0.11	0.11±0.01[a]	0.09-0.12	0.13	0.11	0.12	0.12±0.01[a]	0.11-0.19
	Cd	0.08	0.07	0.11	0.09±0.02[a]	0.07-0.11	0.11	0.10	0.09	0.10±0.01[a]	0.09-0.11
	Hg	0.01	0.01	0.02	0.01±0.00[a]	0.01-0.02	0.01	0.01	0.02	0.01±0.00[a]	0.01-0.02
	As	0.001	0.001	0.002	0.001±0.00[a]	0.001-0.002	0.001	0.001	0.002	0.001±0.00[a]	0.001-0.002
	Se	0.002	0.004	0.003	0.003±0.00[a]	0.002-0.004	0.004	0.004	0.006	0.005±0.00[a]	0.004-0.006

Means with the different superscripts across the row indicates significant ($p < 0.05$, ANOVA) difference in metals concentratio metals content of *T. occidentalis* harvested from the different quarries were found to be significant both in dry and wet seasons (ANOVA, $p \leq 0.05$; Figure 2 and 3). Metals contents of *T. occidentalis* harvested near the quarries were found to be significantly higher than the control stations (ANOVA, $p \leq 0.05$). The difference in metal contents of *T. occidentalis* between dry and wet seasons were also significant at 95% confidence level (Table 2).

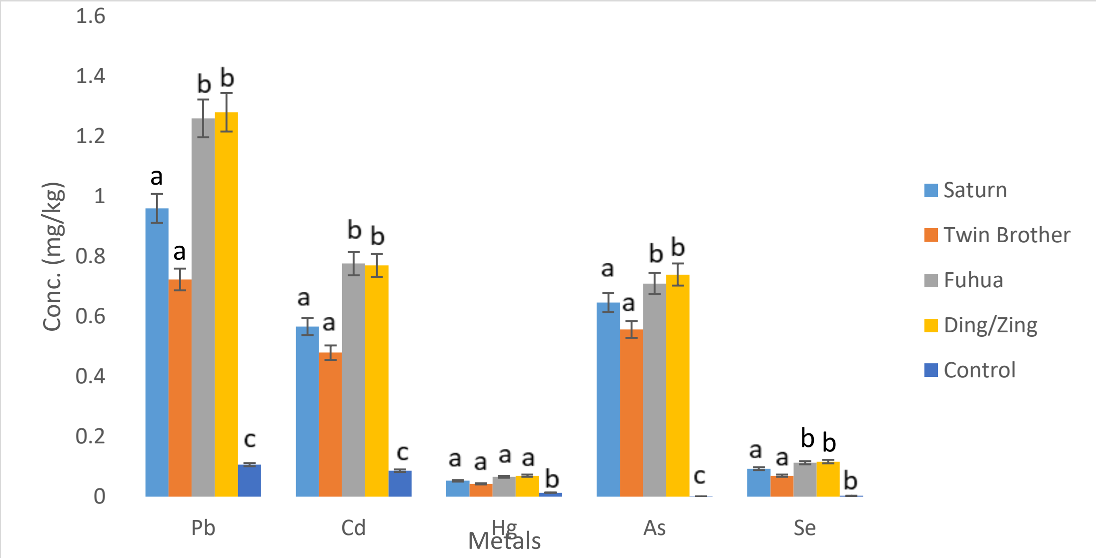

FIG 2: Comparison of heavy metal concentration in fluted pumpkin cultivated around quarries and control for dry season

Quarries with different superscript per metal indicates significant difference (ANOVA, $p < 0.05$) in concentration

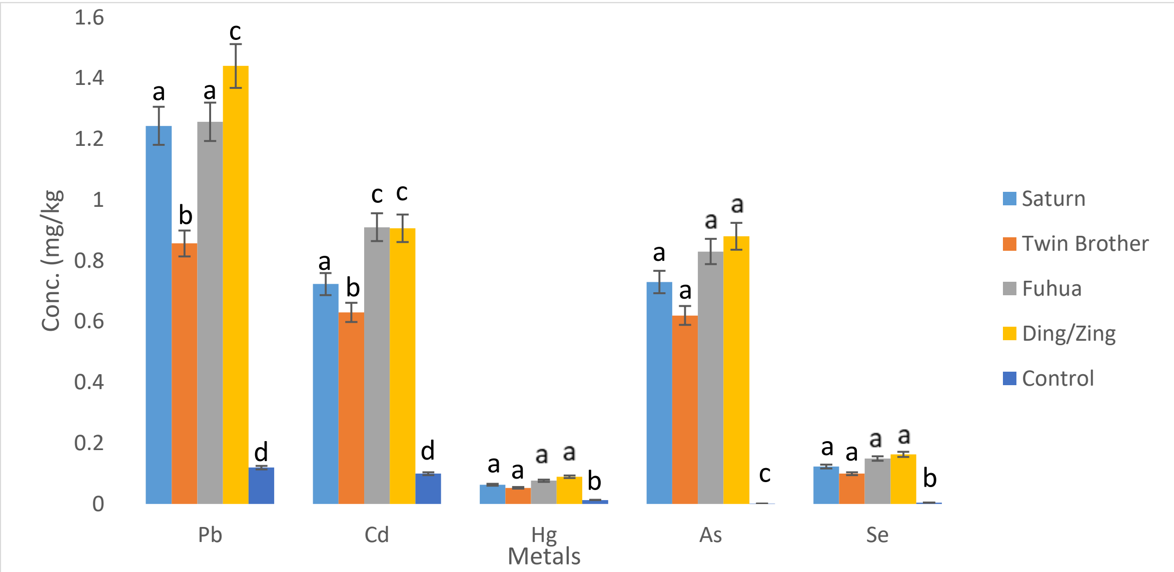

FIG. 3: Comparison of heavy metal concentration in fluted pumpkin cultivated around quarries and control for wet season

Quarries with different superscript per metal indicates significant difference (ANOVA, $p < 0.05$) in concentration

Table 3: Relationship between heavy metals concentrations in fluted pumpkin cultivated around quarries

		lead pumpkin	cadmium pumpkin	mercury pumpkin	arsenic pumpkin	selenium pumpkin
lead pumpkin	Pearson Correlation	1				
	Sig. (2-tailed)					
	N	30				
cadmium pumpkin	Pearson Correlation	.959**	1			
	Sig. (2-tailed)	.000				
	N	30	30			
mercury pumpkin	Pearson Correlation	.942**	.957**	1		
	Sig. (2-tailed)	.000	.000			
	N	30	30	30		
arsenic pumpkin	Pearson Correlation	.944**	.969**	.934**	1	
	Sig. (2-tailed)	.000	.000	.000		
	N	30	30	30	30	
selenium pumpkin	Pearson Correlation	.928**	.965**	.925**	.941**	1
	Sig. (2-tailed)	.000	.000	.000	.000	
	N	30	30	30	30	30

**. Correlation is significant at the 0.01 level (2-tailed).

Table 4: Estimated Daily Intake (mg/kg b.w / day) of metals

	Pb		Cd		Hg		AS		Se (µg/kg)	
	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season
Saturn	0.94	1.21	0.56	0.71	0.05	0.05	0.64	0.72	0.09	0.12
Twin Brother	0.71	0.84	0.47	0.61	0.04	0.05	0.55	0.61	0.06	0.1
Fuhua	1.23	1.23	0.71	0.89	0.06	0.08	0.7	0.81	0.11	0.15
Ding Zing	1.79	1.4	0.7	0.89	0.06	0.09	0.72	0.86	0.12	0.16
Average	**1.17**	**1.17**	**0.61**	**0.78**	**0.05**	**0.07**	**0.65**	**0.75**	**0.10**	**0.13**
Control	0.11	0.10	0.08	0.09	0.01	0.01	0.001	0.001	0.003	0.005
UL (mg/day)	**0.240**	**0.240**	**0.064**	**0.064**	**ND**	**ND**	**1-3**	**1-3**	-	-
RDI (mg/day)	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.5-1**	**0.5-1**	**33-34 (25-26)**	**33-34 (25-26)**

TABLE 5: Target Hazard Quotient

	Pb		Cd		Hg		AS		Se	
	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season
Saturn	0.296	0.345	0.557	0.707	0.178	0.178	2.141	2.392	0.017	0.023
Twin Brother	0.201	0.238	0.471	0.610	0.142	0.178	1.820	2.035	0.012	0.019
Fuhua	0.351	0.352	0.760	0.889	0.214	0.250	2.320	2.713	0.021	0.030
Ding Zing	0.51	0.401	0.750	0.889	0.214	0.286	2.391	2.856	0.024	0.032
Average	**0.340**	**0.334**	**0.635**	**0.774**	**0.187**	**0.223**	**2.168**	**2.499**	**0.019**	**0.026**
Control	0.03	0.035	0.086	0.086	0.036	0.037	0.003	0.03	0.0006	0.001

The mean lead concentrations in fluted pumpkin leaves and tender stems were found to exceed the European Commission's maximum level (EC, 2015) and the FAO/WHO permissible limit (FAO/WHO, 2014) of 0.30 mg/kg for leafy vegetables. This suggests that consumption of *Telfairia occidentalis* grown near quarries, particularly when consumed at typical Nigerian intake rates, could significantly impact human health, potentially leading to lead poisoning. Lead is a prioritized hazardous material that remains toxic at even low levels, with the nervous system being the most commonly affected in both children and adults (Merh, 2020). Given lead's lack of a safe exposure threshold, its presence in fluted pumpkin grown near quarries is of serious concern. Cadmium, a cumulative toxicant with a long biological half-life, also posed significant risks. This study found cadmium levels exceeding both the European Commission's and FAO/WHO's maximum permissible limits of 0.2 mg/kg (EC, 2014; FAO/WHO, 2014). Cadmium is primarily ingested through food, and it is associated with various health issues, including kidney damage, decreased bone calcium levels, reproductive and endocrine dysfunctions, and cancer. Notably, previous research has shown higher cadmium concentrations in fluted pumpkin leaves and stems grown near quarries in Akamkpa, Cross River State, Nigeria, with reported values of 25.58 mg/kg and 18.05 mg/kg, respectively (Ekpo, Nzegblue, & Asuquo, 2011). Its toxicity is compounded by its ability to cross the placenta, making it especially harmful to fetuses (Ahiakwo et al., 2019; Nnamonu et al., 2015).

Mercury exposure is primarily through inhalation and ingestion of contaminated food. While the mercury levels recorded in this study were below the FAO/WHO limit of 0.5 mg/kg (FAO/WHO, 2014), long-term exposure remains a concern due to its cumulative effects. Mercury can affect the central nervous system, cardiovascular system, and kidneys, with its methylmercury form being particularly harmful to fetal neurological development (Daniel et al., 2016). Though levels in this study were below regulatory limits, they still warrant concern. Chronic exposure to arsenic can lead to a range of severe health issues, including skin lesions, cardiovascular disease, and cancer (ATSDR, 2007). The JECFA Provisional Tolerable Daily Intake (PTDI) for inorganic arsenic is 0.002 mg/kg body weight, equivalent to 0.12 mg/day for a 60.7 kg adult (FSAI, 2009). The arsenic levels in this study were below the PTDI, suggesting no immediate risk for individuals consuming the average daily intake of 65g of vegetables, which is typical for Nigerians. However, long-term exposure to even low levels can have serious health consequences (Daniel et al., 2016). Selenium, while an essential nutrient, can become toxic at high concentrations, leading to symptoms such as muscle tenderness, nausea, vomiting, and even liver and kidney damage. The Tolerable Daily Intake for selenium is 6.4 µg/kg body weight/day, equivalent to 0.338 mg/day for a 60.7 kg adult (Environment Agency, 2009). In this study, selenium concentrations in fluted pumpkin were found to be below the tolerable daily intake for typical Nigerian consumption, suggesting no immediate selenium toxicity risk. The findings also highlight a significant difference in metal concentrations between fluted pumpkin plants grown near quarries and those from control stations, suggesting a clear impact of the quarry environment on metal accumulation. This emphasizes the need for ongoing monitoring and regulation to safeguard public health in areas with potential environmental contamination.

Table 6: Incremental Lifetime Cancer Risk (ILCR) and Cumulative Cancer Risk (CCR)

Quarreis	Dry Season						Wet Season					
	Pb	Cd	Hg	As	Se	CCR	Pb	Cd	Hg	As	Se	CCR
Saturn	$8.0x10^{-5}$	$8.4x10^{0}$		$9.6x10^{-3}$		$9.4x10^{-2}$	$1.00x10^{-4}$	$1.1x10^{-1}$		$1.1x10^{-2}$		$1.1x10^{-1}$
Twin Brother	$6.0x10^{-5}$	$7.1x10^{0}$		$8.3x10^{-3}$		$7.9x10^{-2}$	$7.1 x10^{-5}$	$9.2x10^{0}$		$9.2x10^{-3}$		$1.1x10^{-1}$
Fuhua	$2.0x10^{-3}$	$1.1x10^{1}$		$1.1x10^{-3}$		$1.2x10^{-1}$	$2.1 x10^{-3}$	$1.3x10^{1}$		$1.2x10^{-2}$		$2.8 x10^{-2}$
Ding Zing	$1.5x10^{-5}$	$1.0x10^{1}$		$1.1x10^{-2}$		$1.2x10^{-1}$	$1.2 x10^{-4}$	$1.3x10^{1}$		$1.3x10^{-2}$		$2.9x10^{-2}$

Relationship between heavy metal in fluted pumpkin cultivated around quarries

The strong, positive correlations observed between lead and cadmium, lead and mercury, lead and arsenic, and between lead and selenium (Table 12) indicate that an increase in lead concentration in fluted pumpkin is associated with corresponding increases in these metals, suggesting a common source of contamination. Similarly, the significant correlations between cadmium and mercury, cadmium and arsenic, and cadmium and selenium reveal that higher cadmium levels are linked to increases in these other metals, further supporting the idea of a shared source. Finally, the strong correlations between mercury and arsenic, mercury and selenium, and arsenic and selenium indicate that as the concentration of one metal rises, so does the concentration of the others, again pointing to a single source responsible for their accumulation in the crop

Evaluation potential human health risk due to consumption of fluted pumpkin (*Telfairia occidentalis*) cultivated around the quarries

Estimated Daily Intake (EDI): The average estimated daily intake of Pb, Cd, and Hg exceeded the recommended daily intake (RDI) for the metals, while As and Se remained within acceptable limits. Moreover, the intake levels of lead and cadmium surpassed the upper tolerable limits. The average daily intake values were calculated per kilogram of body weight per day (mg/kg b.w/day), for an average Nigerian adult weighing 60.7 kg. For instance, the EDI for lead in fluted pumpkin during both the wet and dry seasons was found to be 1.17 mg/kg b.w/day, which equates to a daily intake of 71.02 mg for an adult each season. These findings suggest that long-term consumption of fluted pumpkin from areas surrounding these quarries poses a significant health risk due to lead, cadmium, and mercury exposure.

Target Hazard Quotient (THQ): THQ is the ratio of the metal's estimated daily intake (EDI) to its reference dose (RfD), which represents a lifetime exposure level considered safe without adverse health effects (Guerra *et al.,* 2012; Lanre-Iyanda & Adekunle, 2012). A THQ below 1.0 indicates no significant risk. In this study, the average THQs for all metals were found to be below 1.0, except for arsenic. This implies that, while arsenic exposure could present a risk, for most metals, the individual consumption of fluted pumpkin from these areas does not pose an immediate health concern based on the THQ.

Hazard Index (HI): Hazard Index assumes that the combined effects of metal exposure will be proportional to the sum of each individual metal's impact. A HI greater than 1 indicates a potential health risk. Although the THQs for individual metals were below 1.0, the combined HI for both the dry and wet seasons was above 1.0 for a typical adult (60.7 kg), suggesting a significant health risk due to cumulative exposure to the metals present in fluted pumpkin.

***Incremental Lifetime Cancer Risk (ILCR)* :** The acceptable cancer risk level for carcinogens is generally between 10^{-6} and 10^{-4}, with risks above 10^{-4} considered unacceptable **(**US-EPA, 2010; IACR, 2021**)**. The calculated cancer risks for cadmium and arsenic in fluted pumpkin grown near all quarry sites exceeded the regulatory limit of 10^{-4}, indicating a significant carcinogenic risk. Lead, however, posed a carcinogenic risk only in the case of fluted pumpkin from Fuhua Quarry. These findings underscore the carcinogenic threats posed by cadmium, arsenic, and lead in the studied pumpkin samples.

Cumulative Cancer Risk (CCR): The cumulative cancer risk due to exposure to cadmium, lead and arsenic via the consumption of fluted pumpkin from the study area was also found to be above the standard tolerable regulatory risk for carcinogens (10^{-4}) indicating significant carcinogenic risk.

Conclusion: Quarrying activities release particulate matter and other contaminants including heavy metals into nearby farmland soil, facilitating metal uptake by crops. Thus, fluted pumpkin cultivated near quarries showed elevated metal concentrations compared to control samples, with lead (Pb) and cadmium (Cd) exceeding FAO/WHO permissible limits for leafy vegetables. Estimated daily intake for Pb, Cd, and mercury (Hg) surpassed recommended limits, with Pb and Cd exceeding upper tolerable thresholds. Arsenic's Target Hazard Quotient (THQ) and the Hazard Index (HI) for all metals were above 1, indicating significant health risks. Incremental Lifetime Cancer Risk (ILCR) and Cumulative Cancer Risk (CCR) for Cd, arsenic, and Pb exceeded acceptable thresholds, highlighting serious toxicological and carcinogenic risks from consuming fluted pumpkin grown near quarries.

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